THE SMALL SIZE DEBRIS POPULATION AT GEO FROM OPTICAL OBSERVATIONS

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ABSTRACT

We have observed the geosynchronous orbit (GEO) debris population at sizes smaller than 10 cm using optical observations with the 6.5-m Magellan telescope 'Walter Baade' at the Las Campanas Observatory in Chile. The IMACS f/2 imaging camera with a 0.5-degree diameter field of view has been used in small area surveys of the GEO regime to study the population of optically faint GEO debris. The goal is to estimate the population of GEO debris that is fainter than can be studied with 1-meter class telescopes. A significant population of objects fainter than $R = 19^{th}$ magnitude has been found. These objects have observed with angular rates consistent with circular orbits and orbital inclinations up to 15 degrees at GEO. A sizeable number of these objects have significant brightness variations ("flashes") during the 5-second exposure, which suggest rapid changes in the albedo-projected size product.

1 INTRODUCTION

Optical surveys of objects at geosynchronous orbit (GEO) are the usual mode of estimating the population of objects in the GEO regime, both controlled and uncontrolled. To date, optical surveys have been conducted using 1.0-m class telescopes [1][2][3]. This has resulted in the detection of GEO objects down to approximately 20 cm in size, assuming an albedo of 0.2 and using short exposure times (a few seconds).

To reach smaller sizes, and hence fainter objects if the albedo is assumed, one must keep the exposure time short and use a larger telescope. Just increasing the exposure time on a small telescope is counterproductive for two reasons:

1. The background stars are streaks, which increase in length as the exposure time is increased. This is contamination and can result in a lower detection rate for GEO objects.
2. The uncontrolled GEO debris population is on a range of orbits, which have different observed angular rates and position angles of motion. Increasing the exposure time decreases the sensitivity due to streak losses. (If all GEO debris was on the same orbit, then this would not be true, one would track at the expected rate, and the exposure time could be increased subject to condition 1.)

Therefore the only way to reach fainter magnitudes (and hopefully smaller sizes if the albedo is the same) with a short exposure time is to use a larger telescope.

What can be learned by observations of debris in the GEO regime with existing astronomical telescopes and instruments? Quite a lot, it turns out. We report on observations of GEO debris obtained with the 6.5-m Magellan telescope 'Walter Baade' at the Las Campanas Observatory in Chile.

2 OBSERVATIONS

The Magellan telescopes are a pair of 6.5-m aperture optical telescopes at the Las Campanas Observatory in Chile. A consortium consisting of the Carnegie Observatories, Harvard University, the Massachusetts Institute of Technology, the University of Michigan, and the University of Arizona runs them. The telescope time used for this project was obtained through a competitive time allocation process at the University of Michigan's Department of Astronomy.

The instrument used was the IMACS (Inamori-Magellan Areal Camera and Spectrograph)[4] in f/2 imaging mode. Constructed for spectroscopy of galaxies, this instrument has the widest field of view

(fov) of any imaging camera on either Magellan telescope: 0.5 degree diameter, or approximately the diameter of the full moon. This fov is small compared with that used by smaller telescopes for GEO surveys (typically 1 degree or more). The expectation was that if the debris population increased significantly as one went to fainter magnitudes (and thus smaller sizes assuming a constant albedo) the number of detected objects would be significant even in a small fov. This expectation was met.

The detector is a mosaic of 8 thinned E2V CCDs, with a small gap between them. Exposure times were 5 seconds. Filters used were a Sloan r' filter for initial tests, followed by a wide band 480-780 nm filter for most of the observations. Standard star fields were observed for photometric calibration.

All GEO observations were taken as close to Earth shadow as possible without being in eclipse. Fields were selected where uncontrolled GEO objects were predicted to be based on theoretical models of GEO motion for low Area-to-Mass Ratio (AMR) objects. No input catalog was used to plan the observations, except for a few observations of cataloged objects from confirmed breakups of Titan 3C Transtages at GEO.

The CCDs were binned 2x2 to speed up readout time and minimize overhead. A new 5-second exposure began every 37 seconds. Effective pixel size was 0.4 arc-seconds, compared with delivered image quality of 0.5 to 1.0 arc-seconds Full Width Half Maximum (FWHM).

A standard exposure sequence involved 24 five-second images before moving to a new field.

The telescope tracking rates were set to zero (motionless), which would be correct for a station-kept object at GEO. Predicted rates of GEO objects were symmetric about this motion. Stars are then streaks moving in an East-West direction. A few observations were obtained of Titan 3C Transtage objects (see above) at their predicted rates.

Standard CCD reduction techniques of bias overscan subtraction and flat fielding were applied to the raw CCD images

Fig. 1 shows a typical 5 second exposure with the Magellan IMACS camera.
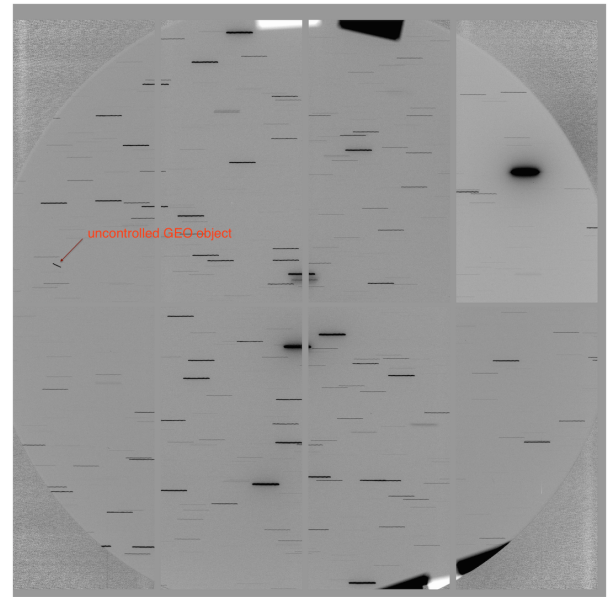

Figure 1. A 5 second exposure of a GEO field obtained with the eight CCDs of the IMACS f/2 camera on the 6.5-m Magellan telescope 'Walter Baade'. The grey areas at the corners are due to vignetting in the camera optics. White/black areas at top and bottom are guide probes. Stars are horizontal streaks, while an uncontrolled GEO object is at the left center.

3 RESULTS

A significant number of objects were detected down to a limiting magnitude fainter than R = 20 and with angular motions consistent with them being in the GEO regime . Our expected rates for low AMR objects on circular orbits with inclination less than 15 degrees are

- |Hour Angle rate| <= 2 arc-seconds/second
- |Declination rate| <= 5 arc-seconds/second

For a detection to be considered real,:

1. It had to be detected in at least two images in a sequence.
2. The detections had to have similar streak lengths and position angles.

For survey observations with the 0.6-m MODEST [2], the detected rate for objects with R between 15th and 18th magnitude was approximately 1 GEO object/square degree/hour. There was a wide variation in the detection rate depending on time of year and topocentric declination of observation. For Magellan, the detection rate for objects between 18th and 20th R magnitude was approximately 5-10 objects/square degree/hour. There is a wide range in detection rates here as well.

The MODEST and Magellan survey techniques are very different, however. A direct comparison of the two rates depends on understanding better how to normalize survey data from two different telescopes with different

survey techniques. This work is in progress.

We conclude that there is a significant population of optically faint (and presumably small sized) debris with angular rates consistent with being in the GEO regime.

4   BRIGHTNESS VARIATIONS

The Magellan detections fall into three different categories as regards brightness variations during a 5 second exposure. The figures below show four sequential images of each of these categories. Note that if we were tracking at exactly the object's angular rate, we would not have been able to make these measurements.

1. Constant brightness streaks. There is no or very small brightness variation during the 5-second exposure. See Fig. 2.

Figure 2. A GEO object moving at constant brightness in four sequential images. Any change in brightness must be over a much longer time than the 5-second exposure. The horizontal streak is a background star.

2. A streak with one well defined minimum during the 5-second exposure. One interpretation is that the period is roughly the same as the exposure time. See Fig. 3 below.
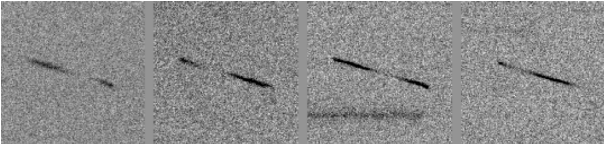

Figure 3. A GEO object with one well-defined minimum during the 5-second exposure. There could very well be multiple minima in one period if we had exposed longer.

3. Objects with multiple maxima during the 5-second exposure. Two examples are shown below. In Fig. 4 there are multiple maxima of unequal duration. In Fig 5 there are 4 or 5 maxima of similar duration.
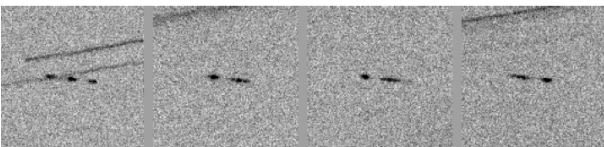

Figure 4. Sequential images of a GEO object with multiple brightness maxima of different lengths.
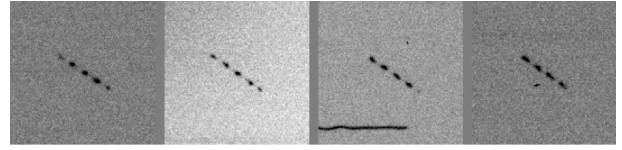

Figure 5. Sequential images of a GEO object with multiple well-defined maxima of similar brightness.

This last case is particularly interesting. All GEO objects are spatially unresolved with this instrument. The width of the brightness maxima perpendicular to the streak gives an estimate of the image quality, in this case 0.7 arc-seconds FWHM. Along the streak direction the observed width is the convolution of the image quality (seeing) with brightness changes. Some of these maxima are just barely resolved. If the object is moving at 5 arc-second/sec along-track, the FWHM of the seeing disk is crossed in 0.14 seconds. Then the maxima are of this time length or slightly greater. This is very rapid variation in brightness. The brightness variation reflects the product of albedo times size. What sort of objects are these, and if they are tumbling, what is the mechanism that causes such rapid changes?

The maxima in Fig. 5 are R = 19.5, or the brightness expected from a 10-cm sized object like a 1U CubeSat or a small iPhone. (The authors are not concluding that there are 1U CubeSats at GEO nor that GEO debris consists of iPhones, only that a 6.5-m telescope can detect objects of such a size in the GEO regime.)

5   CONCLUSIONS

Observations with the 6.5-m Magellan telescope 'Walter Baade' and the IMACS f/2 imaging camera have detected a significant population of optically faint objects with angular rates consistent with them being at GEO. Assuming an albedo of 0.2, their sizes are in the 10 cm range. Their optical appearance varies from no brightness variations in a 5-second exposure to multiple brightness maxima. The shortest maxima correspond to just a few tenths of a second in time.

6   ACKNOWLEDGEMENTS

7   REFERENCES

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